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GENERAL REGULARITIES OF THE REACTION OF THE HUMAN ORGANISM TO THE COMBINED INFLUENCE OF ENVIRONMENTAL FACTORS CHARACTERISTIC FOR A SPACECRAFT CABIN

A. V. Lebedinskiy, S. V. Lebinskiy
and Yu. G. Nefedov

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The problem of studying the system of reactions of the human /77* to extended residence in a sealed chamber of limited volume has become quite important in recent years for a number of areas of human activity. We must emphasize that the solution of this problem is facilitated by the possibility of organization of various experiments under laboratory conditions involving human volunteers, imitating the conditions of certain environments.

As a model for the solution of general problems in this area, sealed-chamber experiments were conducted, lasting from 10 to 120 days, during which the medium formed in the chamber as a result of the presence of the human subjects and the reactions of the subjects to life in the sealed chamber were studied. These experiments also imitated certain other influences: ionizing radiation in low doses, periodic elevation of temperature, noise and other factors.

In a sealed chamber, the relationship between man and his environment is somewhat different from that encountered in everyday life. Whereas under ordinary conditions we primarily see a dependence of the processes of human vital activity on influences of the medium, in the sealed chamber the reverse dependence also begins to appear quite clearly -- dependence of changes in the medium on processes of human living activity. Thus, under these conditions man becomes a determining element in the relationship of changes in the medium; we must emphasize that the changes may have an unfavorable influence on the subject.

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*Numbers in the margin indicate pagination in the foreign text.

This can be illustrated by a few specific examples. /78

Studies of changes in the nonspecific immunization reactivity of test subjects and comparison of these data with changes in the microflora of the environment have indicated a significant increase in the number of microbes per unit volume of air. The reason for this is the significant increase in the number of microorganisms vegetating on the skin, as a result of a reduction in its bactericidal function (S. N. Zaloguyev, Figure 1).

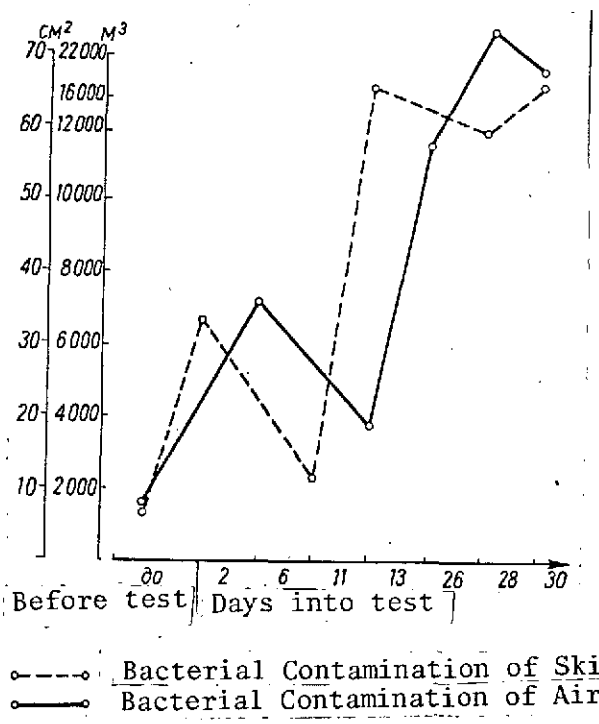

Figure 1. Comparative Data on Variations in Bacterial Contamination of Skin and Air

Sealed chamber experiments have also established that even when there are no artifical sources of CO in the chamber, the air medium still becomes contaminated with carbon monoxide, the source of which is the human subject, whose organism forms carbon monoxide in some, as yet insufficiently studied, biochemical conversion. As it is liberated from the organism and accumulates in the air, the carbon monoxide causes the initial symptoms of carbon monoxide poisoning, due to the reduction in partial pressure difference of this gas in the air exhaled and in the air in the chamber. The fact of carbon monoxide poisoning can be determined both by the appearance of /79 carboxyhemoglobin in the blood, and on the basis of certain changes which occur in the central nervous system (Figure 2).

This dependence is also correct for other substances liberated through the lungs, particularly carbon dioxide. The content of carbon dioxide in the air in the sealed chamber during the tests

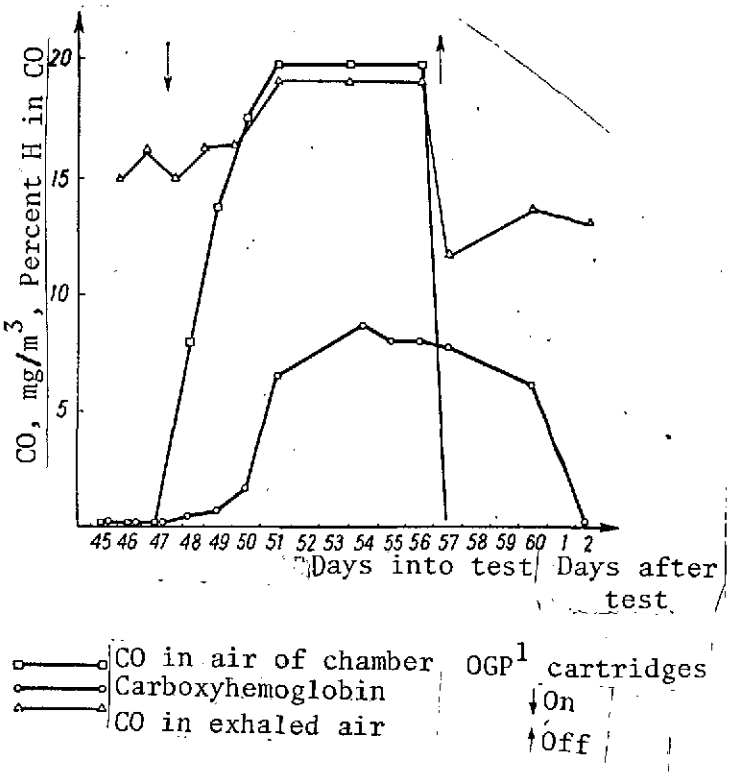

Figure 2. Dynamics of Carbon Monoxide Content in the Air of a Chamber, in Air Exhaled by the Subject and of Carboxyhemoglobin in the Blood of the Test Subject

averaged 0.4-0.6%, 10 to 20 times its content in the atmosphere. This hinders elimination of carbon dioxide through the lungs, causing the CO_2 pressure in the alviolar air and in the blood to increase, influencing the functions of external respiration and dermal gas exchange (L. R. Iseyev). This is particularly clearly seen in the 120-day experiments.

Summing up these data, we must conclude that the reason for the many physiological changes which we will discuss below might be the autointoxication of the subject with products of his own vital activity, liberated through the lungs and not ordinarily accumulated in the large quantities observed in a sealed chamber of limited volume.

Therefore, the limiting permissible concentrations of these /80 substances should be significantly lower than their concentrations in air of exhalation, in order not to prevent their normal elimination from the organism. In particular, for carbon monoxide we recommend a limiting permissible concentration of 3-5 mg/m^3, for carbon dioxide, if the subject will remain in the sealed chamber for over 4 months -- 0.2-0.3%.

[1] Expansion unknown.

Autoinfection may have some significance under these conditions as well. The question of the significance of allergens which may be present in the air medium, formed as a result of the vital activity of the subject, has not been sufficiently studied.

The unique relationships which develop between the organism and the environment in a sealed space, as well as the influence of such factors as ionizing radiation, moderate increases in air temperature and noise, along with the absence of ultraviolet radiation and the effects of limitation of motor activity, i.e., the combination of influences present in most sealed chamber tests, lead to certain changes in the organism, characterizing the reaction of the organism to changes in environmental conditions. The most complete idea of the essence and mechanism of this reaction can be provided by analysis of the physiological changes during individual periods of chamber tests of significant length (60 and 120 days), during which the sequence of development of these changes is most clearly seen.

During the first phase, lasting some 10 to 15 days in 60-day tests, changes are observed which can be generally characterized as the initial reaction to changes in living conditions. This reaction involves the process of restructuring of the organism to a new functional level, corresponding to the changed conditions. At the end of this time, changes in the regulatory mechanisms of circulation and respiration, the functions which largely determine the overall level of functioning of the organism, are completed.

Analyzing the systolic volume and blood volume per minute moved by the heart, an integral indicator of the activity of the circulatory apparatus, we can see that these quantities drop at rest: systolic volume decreases from 50 to 40 ml, volume per minute from 3.75 to 2.7 l. With moderate physical activity, these indicators do not reach their values determined before the beginning of sealed chamber tests. At the same time, a delay in normalization of these indicators 3 minutes following exercise is

observed. These changes must be looked upon as a manifestation of the inertia of the mechanisms regulating the circulatory function (Figure 3).

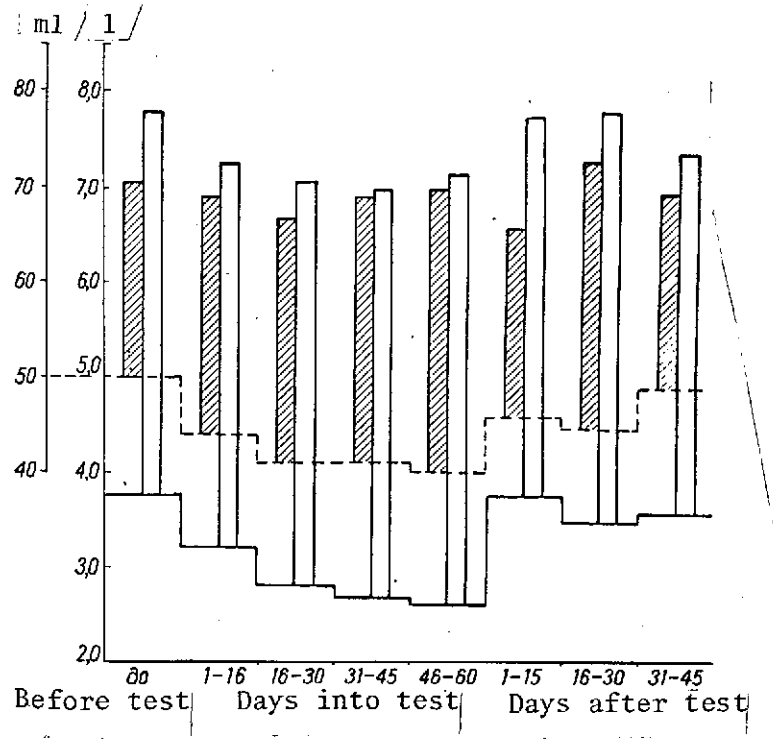

Figure 3. Changes in Systolic Volume and Blood Volume per Minute at Rest and Following Moderate Physical Exercise (Main Data for Six Test Subjects Each 15 Days)

As concerns gas exchange, a certain inertia and imperfection /81 of mechanisms regulating this process have also been observed (L. R. Iseyev). With moderate physical exercise, the consumption of oxygen increased significantly more than before the beginning of the experiment. The process of elimination of the oxygen deficit is also significantly retarded. Thus, the "efficiency" of operation of this system is significantly reduced.

It is quite natural that these changes depend primarily on the unique accommodation of the regulatory mechanisms, most probably due to changes in CNS function, one cause of which is disruption of the primary stereotype. During the initial period of the tests, an inhibitory process is noted in the cerebral cortex (reduction of photosensitivity, according to the data of adaptometry, increased motor reaction time, etc.). This occurs most probably due to external inhibition, although there are also indi- /82
cations of weakening of the process of internal inhibition (increased number of errors in work, disruptions of sleep, etc.). There are also certain indications of changes in the activity of the endocrine system, in particular an increase in the function of the adrenal cortex, which can be seen in the increased liberation of 17-ketosteroids with the urine.

In spite of the fact that a number of unfavorable changes occur in the process of adaptation, the organism adapts itself to the conditions of the altered environment in the sealed chamber. The result is some normalization of many functions: sleep, motor reactions, photosensitivity of the eye, a reduction to some extent in the number of errors in work, etc. However, the increased fatigue remains. Thus, the adaptation is relative and, since the effect of the unfavorable factors continues, the adaptive mechanisms are eventually disrupted and signs of asthenia are observed by the end of the test.

Analyzing the physiological changes in the organism of the test subjects, we will use the term "asthenization." And truly, the combination of such phenomena as reduction in working ability, increased fatigue, changes in sleep function, reduction in immunization reaction, reduction in functional capabilities of the cardiovascular system, changes in the "efficiency" of physical work, plus very specific changes in the dynamics of cortical processes do correspond to current concepts of the asthenic syndrome. Naturally, long before the development of external manifestations of asthenization, disruption of the equillibrium of

nervous processes in the cerebral cortex can be noted.

Particular attention should be given to the changes observed in test subjects as they leave the chamber and return to conditions of daily life. We call these changes the "exit reaction." This reaction includes primarily some deepening of asthenization; the entire complex of phenomena shows a tendency toward long retention. Thus, after 60-day tests, the state of asthenization was retained about 2 months. The mechanism of development of the exit reaction apparently consists in that, as a result of extended exposure to the conditions of the chamber, a unique and firmly fixed stereotype is established, disruption and replacement of which is even more difficult than adaptation to the conditions in the chamber, so that the very adaptive capabilities of the /83
organism are weakened by the long exposure to the unfavorable factors during the test.

It should be emphasized that a transition from one set of living conditions to others can be made in a very short period of time. Therefore, the less the conditions of existence in the sealed chamber differ from ordinary conditions, the less sharply will the exit reaction be manifested. Our experience from 120-day tests showed that the use of a combination of treatment measures during the late stages of the test (additional purification of the air to remove bacteria and harmful chemical impurities, ultraviolet irradiation of the skin of the test subjects, inclusion of an increased quantity of vitamens in the rations of the subjects, the use of a special set of physical exercises and certain medicines), as well as the organization of a gradual transition of the test subjects back to ordinary living conditions, facilitated a significant decrease in the degree and duration of the exit reaction.

When the human organism is subjected to the simultaneous effects of several environmental factors, from the practical standpoint it is significant to have an idea as to which factor is leading, what are the roles of the remaining factors and which

of them should be given the most attention by the hygienist in answering questions concerning improvement of the environment. Along with this, analysis of the significance of the factors present allows us to study such physiological regularities as the specificity of the reactions to stimuli, the phenomenon of addition of the effects of various stimuli, etc.

In our experiments on the human organism, factors were involved which developed upon long exposure to the conditions in a sealed chamber of limited volume, with no ultraviolet radiation and significant limitations of motor activity: ionizing radiation in small doses, noise, elevated air temperature. It should be emphasized that most of the factors present (concentrations of CO_2, CO and other harmful impurities in the air, absorbed doses of ionizing radiation, etc.) were near their threshold values. Even the air temperature varied within permissible limits most of the time in the main experiments. Under these conditions, the question of the possibility of development of reactions specific for any one of the factors present, for example for ionizing radiation, becomes quite significant. In analyzing the data produced, in most cases we could find no specific reactions.

The changes in such functions as higher nervous activity, /84
circulation, respiration, metabolism and others were not specific and represented expressions of the general reaction of the organism to the unfavorable changes in the environment. This nonspecific reaction meant that the phenomenon of addition of the effects of dissimilar influences was present. We present below a rather convincing example of this addition.

The data presented (Figure 4) show that as the test conditions became more severe, due to the inclusion of additional factors, the speed of the motor reactions decreases (A. N. Kartsev). Whereas under optimal temperature conditions, the speed of the reaction increased gradually due to training, when the air temperature was increased to 40-47° it dropped rapidly, exceeding the initial level only toward the end of the test.

Inclusion of the additional factors of noise and ionizing radiation in other experiments caused even more significant slowing of the reaction, which did not reach its initial level even at the end of the experiment.

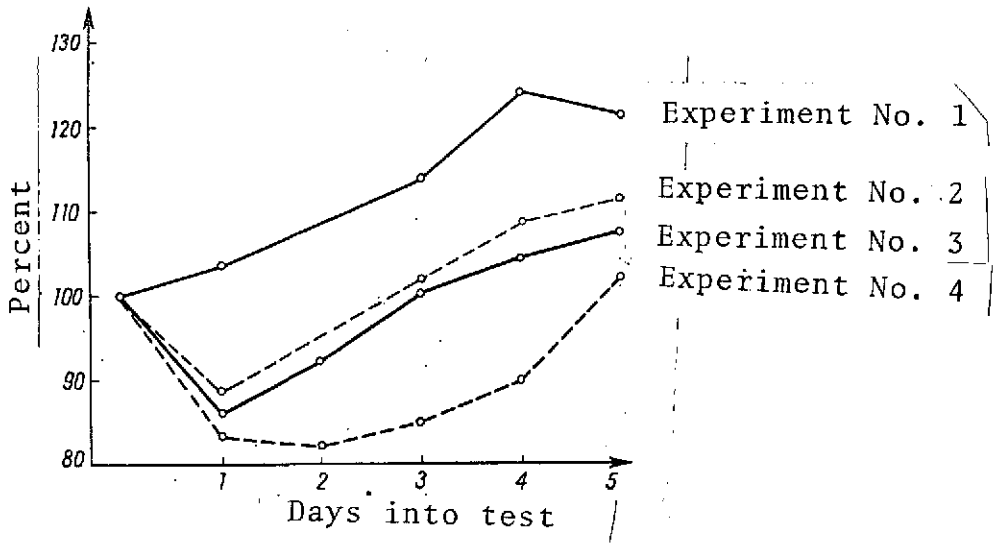

Figure 4. Changes in "Autotemp" Motor Reaction as Functions of Test Conditions (in Percent of Initial): Experiment No. 1 -- t + 23° C; Experiment No. 2 -- t + 40 - 47° C; Experiment No. 3 -- t + 40 - 47° C, Noise -- 105 db; Experiment No 4 -- t + 40 - 47° C, Noise -- 105 db, Gamma Radiation 4.2 μr/sec

The addition of the nonspecific effects of dissimilar irritants can be seen quite clearly in the analysis of the daily elimination of amino compounds by the test subjects in tests with different experimental conditions. When ionizing radiation or /85 intensive noise were included in the test factors, the daily elimination of amino compounds increased in both cases by approximately 40%; when both factors were present simultaneously, elimination was increased by 80%. This example shows that in certain cases, the addition of the effects of dissimilar irritants is approximately absolute, and different factors may be physiologically equivalent.

Nevertheless, in spite of the general nonspecificity of the reactions, in some cases certain changes characteristic for the influence of one factor or another may appear. An example is the appearance of carboxyhemoglobin in the blood when carbon monoxide is present in the air, as well as an increase in the number of erythrocytes under these conditions. There is particular interest in the question of the possibility of appearance of reactions specific for ionizing radiation. Analysis of the blood (N. I. Suprunenko) showed that in some cases, a specific depressing influence of ionizing radiation on leukopoiesis may appear (Figure 5). However, this is observed only if the radiation dose is over 0.3 r/day and when its influence is combined with the influence of such factors as noise and elevated temperature. In this case, the other unfavorable factors seem to potentiate the specific influence of the ionizing radiation. This factor must be considered in answering the question of permissible levels of radiation. In other words, the better the general environmental conditions in the cabin of a spacecraft, the greater the resistance of the astronauts to the effect of ionizing radiation before the risk of serious disruptions in health arises.

One prerequisite for addition of the physiological effects of several dissimilar irritants is that they be applied simultaneously. This simultaneity may cause effects to appear even if the intensity of each individual factor is near its threshold value. On the other hand, the unfavorable factors act continuously over a long period of time. This fact leads at first to development of some relative adaptation in the organism, but also causes gradual accumulation of the physiological effects, causing disruption in the adaptive and regulatory mechanisms, leading, finally, to asthenization. Phenomena of accumulation of the physiological effect are also indicated by the clear dependence between the manifestation of reactions and the length of time the subject spends in the sealed chamber.

The answer to the question as to which of the factors acting /86
on the human organism in the present experiments was most important in the development of the physiological changes observed was produced by combining various versions of tests. It was established that the changes observed with ionizing radiation, increased temperature and noise were least when the chamber was ventilated with outside air. In the experiment with ventilation, there were practically no changes in the blood and cardiovascular system, and the changes of the central nervous system were slight. Thus, we must assume that the air medium and, probably, the chemical composition of the air formulated in the sealed chamber are the most significant factors influencing the human organism under these conditions.

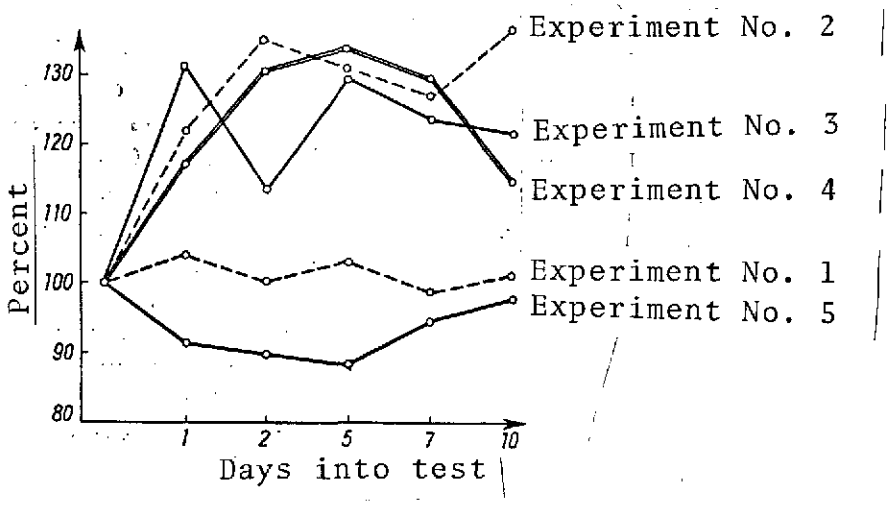

Figure 5. Changes in the Number of Leukocytes as Functions of Experimental Conditions (in Percent of Initial Level): Experiment No. 1 -- Chamber Unsealed, 0.3 r/day, t + 28-34° C; Experiment No. 2 -- Chamber Sealed, t + 28-34° C; Experiment No. 3 -- Chamber Sealed, 0.05 r/day, t + 28-34° C; Experiment No. 4 -- Chamber Sealed, 0.3 r/day, t + 28-34° C; Experiment No. 5 -- Chamber Sealed, 0.4 r/day, t + 28-34° C. The figure shows data for the first 10 days of a 15-day experiment.

It follows from this that the creation of the most favorable possible conditions of the "air environment" is a significant problem.

When living in a sealed chamber, man is subjected to the influence of mental factors, in addition to the purely physical factors which are determined by the unique environment. The most significant of these are the forced isolation from the external world, disruption of the subjects normal conditions of life and, finally, the very "differentness" of living conditions, accompanied by significant limitations on incoming information. Acting through the second signal system, they go far to determine the development of the physiological changes which we have discussed. In addition to these, we noted certain, though slight, changes in the nervous and mental state of our test subject. They were manifested as increased irritability, resulting in somewhat more frequent development of conflicts than under ordinary circumstances; insome cases, slight depression was observed. However, in general, the mental state of the test subjects was quite satisfactory, and these deviations had no serious influence on the course of the experiments. This resulted largely from the fact that during the tests, such positive stimulae were present as precise knowledge of the goals and tasks of the experiments, a sense of responsibility for the work at hand and a spirit of teamwork. It was also present that, while in the chamber, the test subjects spent much of their time performing useful work. This helped not only to smooth out the deviations noted, but to some extent to compensate for the development of such unfavorable neurosomatic reactions as asthenization. /87

In this respect, very interesting data were produced in the analysis of the time periods before appearance of certain changes as functions of the test duration. For example, changes in the central nervous system, as indicated by EEG data, were significantly more clearly expressed in the 10-day tests than in the first 10 days of a two month experiment, while during the first month of a four month experiment the EEG of the test subjects was even somewhat more stable than during the initial control period. Asthenization generally occurred only toward the end

of the experiments, regardless of their duration: 120, 60, 30 or 10 days. All of this indicates the significant role of "adjustment" to the predetermined test duration and the significant influence of the second signal system on the vegetative functions of the organism.

Among the unfavorable factors mentioned above, the uniformity of the conditions of life, resulting from standardization of the work, rest and food schedules, occupies a special position. The problem is that whereas limitation of incoming information in itself has an unfavorable influence, standardization of living conditions, maintaining a strict daily schedule, as we know, also has a positive aspect, particularly if we consider that all of the test subjects were healthy young people. The standardization /88 of the living conditions of the test subjects forced the development of a new stereotype of the flow of most physiological functions. As we analyzed the results of the physiological studies, our attention is drawn not by the slight individual differences, but mostly by the similar nature of changes in most functions for all test subjects. This stereotype nature is particularly clearly seen as we analyze data on working efficiency and fatigue processes. The changes of these indicators for the individual test subjects differ slightly only in degree of expression; as concerns their direction and time of appearance, they are the same for all test subjects. We cannot at present state whether this standardization of the reactions of the test subjects is favorable or not; we can only assume that it is a characteristic physiological phenomenon, illustrating the close dependence of the functions of the organism on the conditions of the environment.

However, it should not be thought that the individual peculiarities of the test subjects did not appear at all. The individual differences depend on whether the test subject is participating in an experiment for the first time or whether it is a repeat experiment for him. They are particularly clearly seen in analysis of dynamics of the change of body weight, as well as

nonspecific immunity reactions. We should emphasize there that subjects who had taken part in sealed chamber experiments earlier generally showed less physiological changes.

The existence of individual differences both in higher nervous activity and in vegetative functions for the participants in the tests forces us to turn more attention to the compatibility of certain people who must live together for long periods of time and work together in limited, generally isolated spaces. Up to now, attention has been primarily turned to problems of mental compatibility: what should be the characteristic peculiarities of individual members of a crew, to produce combinations least likely to result in serious conflicts? Work in this direction is doubtless important, but frequently, the required attention is not given to the fact of the mutual influence of individuals through the second signal system on the characteristic peculiarities inherent for each man. We therefore consider it proper to state the question of the "biological" compatibility of individuals in the broad, general biological aspect.

As we have repeatedly stated before, the environment present /89
in a sealed chamber containing people is formed as a result of the vital activity of the inhabitants. Consequently, individual differences in metabolism will be reflected in different ways in the qualitative and quantitative composition of volatile substances liberated into the air of the sealed chamber by respiration and from the surface of the skin. The qualitative and quantitative composition of microflora in the air of a sealed chamber will also depend on the individual differences of the autoflora. These factors, of course, do not exhaust all aspects of the problem of biological compatibility. However, even in these areas, our knowledge is quite insufficient.

The only thing that we know at present is that there are differences in the quantitative and qualitative composition of autoflora. As concerns the quantitative and qualitative

composition of exhaled air, sweat and certain other volatile excretions of man, the question has not been sufficiently developed. We know noting concerning the mutual influence of individuals with different individual characteristics of these indicators. A great deal of research is needed in this direction, and we believe that space medicine cannot afford to ignore this problem.

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16. Abstract Sealed-chamber studies lasting 10 to 120 days were performed. The medium which formed in the chamber as a result of the presence of the human test subjects and the reactions of the subjects to these conditions were studied. These experiments also imitated certain other effects such as low doses of ionizing radiation, periodic temperature variations, noise and other factors. Several specific examples are presented to illustrate the interrelationship between man and medium in a sealed space.

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